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User Interface Design Guidelines for Smartphone Applications for People With Parkinson's Disease

Francisco Nunes · Paula Alexandra Silva · João Cevada · Ana Correia Barros · Luís Teixeira

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Abstract Parkinson's disease (PD) is often responsible for difficulties in interacting with smartphones; however, research has not yet addressed these issues and how these challenge people with Parkinson's (PwP). This paper specifically investigates the symptoms and characteristics of PD that may influence the interaction with smartphones to then contribute in this direction. The research was based on a literature review of PD symptoms, eight semi-structured interviews with healthcare professionals and observations of PwP, and usability experiments with 39 PwP. Contributions include a list of PD symptoms that may influence the interaction with smartphones, a set of experimental results that evaluated the performance of four gestures tap, swipe, multiple-tap, and drag and 12 user interface design guidelines for creating smartphone user interfaces for PwP. Findings contribute to the work of researchers and practitioners' alike engaged in designing user interfaces for PwP or the broader area of inclusive design.

Keywords Touchscreen accessibility, User interface design, Usability guidelines, Designing for people with special needs, Mobile, Smartphone, Touch gestures, Motor impairments, Parkinson's disease

F. Nunes
HCI group, Vienna University of Technology
Argentinierstraße 8, 2. Stock, 1040 Vienna, Austria
E-mail: francisco.nunes@igw.tuwien.ac.at

P. A. Silva
National University of Ireland, Maynooth
Department of Design Innovation, Maynooth, Kildare, Ireland
E-mail: paula.alexandra@nuim.ie

J. Cevada
Fraunhofer Portugal - AICOS
Rua Alfredo Allen 455, 4200-135 Porto, Portugal
E-mail: joao.cevada@fraunhofer.pt

A. C. Barros
Fraunhofer Portugal - AICOS
E-mail: ana.barros@fraunhofer.pt

L. Teixeira
Faculdade de Engenharia da Universidade do Porto
Rua Doutor Roberto Frias s/n, 4200-465 Porto, Portugal
E-mail: luisft@fe.up.pt

1 Introduction

Parkinson's Disease (PD) is a progressive degenerative disorder that affects the nervous system. It has a high incidence on the older population, as it affects 1-2% of the overall population who are over 65 years old, totalling two million people in Europe [51]. PD symptoms vary greatly from initial to advanced phases of the condition and among different people with Parkinson's (PwP[1]), however, the condition is mostly characterized by motor symptoms, such as tremor or slowness of movement [28]. Non-motor problems may also occur [29]. As the condition progresses, symptoms are likely to reduce the individual's mobility and autonomy, and may force lifestyle changes [14].

The motor symptoms of PD impact multiple everyday activities, including the interaction with smartphones. McNaney et al. [33], for example, reported anecdotal evidence that fine motor skills and tremor can hinder the interaction of PwP with their smartphones. This paper further investigates this subject by evaluating how PwP perform a set of touch gestures and proposing a set of design guidelines for applications for

[1] PwP is a common acronym for naming people with Parkinson's, used for example, by the European PD association (EPDA).

PwP. The work was developed in the context of REMPARK, a European Project focused on delivering a telecare solution, operated by PwP through a smartphone. Given the specificities of PD, interaction with a smartphone is likely to be affected, and thus the purpose of this work.

The objective of this paper is to study how PD affects the interaction with touchscreen handheld devices, from now on referred to as smartphones, to enable the design of more adequate interfaces for PwP. Four research questions underlie this objective: RQ1) How does PD affect the interaction with the smartphone? RQ2) Which symptoms of PD affect the interaction with the smartphone? RQ3) How and to what extent do these symptoms influence the interaction with the device? and RQ4) How can the interaction with smartphones be improved to accommodate the characteristics of PwP?

The main contributions of this paper are the outcomes of a series of usability experiments assessing the quality of tap, multiple-tap, swipe, and drag gestures and a set of user interface guidelines for designing smartphone interfaces for PwP. These are useful for researchers, practitioners, and designers working in this area. Another contribution is a readable and comprehensive review of PD useful for design teams starting to work for PwP.

Having set the scene for this research, we next discuss relevant related work on touchscreen interfaces. The paper then describes the methodology used to address the above research questions. Afterwards, it presents a literature review of the most common symptoms of PD. This is followed by the outcomes of eight semi-structured interviews conducted with health professionals, and informed by observing the symptoms both in-person and online videos. Section 6 describes the usability experiments performed with 39 PwP as well as their results. Combining the findings of these last two research phases, Section 7 contributes with a set of smartphone user interface design guidelines for PwP. The paper concludes with a discussion of the overall methodological approach and results as well as a summary of the findings and future work.

2 Related work

Multiple studies have investigated the use of technologies for PwP, from assistive technologies that improve gait [31,7], to rehabilitation tools [32,39]. This section presents a review of previous work studying the interaction with touchscreens, in particular, studies that focused on PwP, people with motor impairments in their upper limbs, and older people.

2.1 Touchscreen interaction of PwP

Previous research has documented the development of smartphone applications for PwP (e.g. [4,43]) and the use of stylus-based applications designed for PwP (e.g. [17]). However, these studies did not reflect on their experience to then provide user interface design advice, nor did they evaluate systematically the interaction of PwP with their smartphones.

Notwithstanding, the difficulties in interacting with smartphones have been documented. In a study by McNaney et al. [33], PwP reported that fine motor skills and tremor issues hindered their interaction with smartphones. Another study [34] observed 15% error rate in target selection, on an evaluation that included five participants with PD (in a total of nine). The same study also mentioned the varying levels of touch accuracy across test sessions, which can be associated with the symptom fluctuations of PD[2].

As the review is broaden from smartphones to other touchscreen interfaces, studies with more detailed advice are identified. Maziewski et al. [30], for example, designed a tablet interface for PwP and underlined the importance of using large targets to overcome potential issues in vision and fine motor skills. The study also mentioned the importance of using high contrasting elements, for example in labels. These findings contribute to this research, but they are insufficient to drive an informed user interface design of smartphone applications for PwP.

2.2 Touchscreen interaction of people with upper limb motor impairments

While studies focusing on PD are still scarce, previous work exists regarding touch screen interaction of people with motor impairments in the upper limbs. For example, Trewin et al. [47] reported that participants with low dexterity had reduced accuracy when performing tap (˜49%). They also reported that some participants had difficulties performing the swipe gesture. In another study, Duff et al. [12] focused on how people with upper limb impairments interacted with a kiosk interface. Their findings suggest that people with upper limb impairments perform tap gestures with less accuracy and that using 20mm targets avoided performance decrements. However, as [18] state, this size might be hard to accommodate in smartphone interfaces. Another study [20], also using a large touchscreen surface, reported that people with upper limb impairments were slower

[2] Symptom fluctuations are detailed in Section 4.

than non-impaired participants in performing tap gestures. The findings of these studies are not directly applicable to PwP, however, as both PwP and people with upper limb impairments face challenges in their fine motor movements, some of this work might apply to PwP as well.

2.3 Touchscreen interaction of older people

While PD may be diagnosed at younger ages, the condition is more prevalent in older age (60+) segments, therefore some design recommendations targeted at older adults are also applicable to PwP. Similarly to older adults, younger PwP are equally likely to have affected finger dexterity [15], a common issue in older age. It is therefore necessary that previous work on touchscreen interfaces for older people is also reviewed.

Jin et al. [22] conducted one of the first studies focused on finding the appropriate target size for tap gestures that would be suitable for older people interacting with their smartphones. Their results suggested a target of 19.05mm. However, their study setup included a fixed tablet in a specific angle, which is quite different from the normal usage of a smartphone. These target sizes contrast with the 9-10mm suggested by other studies [40, 41]. A more recent study [26] reported that older adults have the best accuracy when tap targets on the smartphone have between 14 and 17.5mm, with 10mm being acceptable when screen space is restricted. The study also reports that targets larger than 17.5mm achieve the best performance for the swipe gesture.

Another characteristic of the condition shared with some older people is tremor. In PwP, tremor appears mostly when the hand is at rest. Nicolau and Jorge [35] tested touchscreen keyboards with older people and concluded that the participants' tremor made more selection errors than the ones without. In another study, Wacharamanotham et al. [50] reported that people with tremor have difficulties performing tap gestures and that for targets smaller than 41mm, swabbing – a gesture that consists of dragging the finger to a target – should be used instead. The applicability of this insight to smartphones is questionable, as the study was performed in kiosk-like interface, which has much more screen space available. Also, there are multiple types of tremor (e.g. essential, rest, etc) and so this finding might not apply to PwP. However, knowing that people with tremor might produce more errors is a relevant insight.

3 Methodology

The overarching goal of this study was to determine how to better design smartphone user interfaces for PwP. Thus four research questions guided this research:

- RQ1: How does PD affect the interaction with the smartphone?
- RQ2: Which symptoms of PD affect the interaction with the smartphone?
- RQ3: How and to what extent do these symptoms influence the interaction with the device? and
- RQ4: How can the interaction with smartphones be improved to accommodate the characteristics of PwP?

The methodological approach undertaken to address these research questions unfolded as described in the following paragraphs.

The research started with a literature review of Parkinson's disease symptoms and characteristics. The goal was to develop an understanding of PD (RQ1), in order to be able to identify possible issues when interacting with smartphone user interfaces (RQ2). The identified issues shaped the usability experiments that were then developed. In a user-centred design perspective, both the relevant scientific medical literature and the perspective of PwP as expressed in publications from patient organisations and other health-related websites, need to be considered. However, having concluded the literature review, the information was still considered inconclusive regarding the specific aspects that could affect the interaction of PwP with smartphones.

Given the insufficient information to adequately design the usability experiments, endeavours were directed to a second phase of research that consisted of eight semi-structured interviews with health care professionals who worked with PwP on a daily basis. These interviews were complemented with observation sessions in which two PwP showed their symptoms to their neurologist, as if it was a consultation. Dozens of online videos with similar content were also visualised. The interviews were audio-recorded, coded, and analysed following the constructivist approach to Grounded Theory (GT) [8]. Together with the observations of PwP, the interviews improved the understanding of the concepts found in the literature review and of the effects of the symptoms in everyday tasks of PwP; this allowed answering RQ2 and proceed with the design of the usability experiments.

The third phase of the research consisted of usability experiments with 39 participants to measure the extent to which the disease affected the interaction with the smartphone (RQ3). Four tests were developed to evaluate the PwP ability to: i) select targets of different sizes; ii) perform repetitive taps; iii) do swipes; and iv) accomplish drag gestures. All interaction data was logged during the experiments and subsequently analysed with repeated ANOVA measures [45].

Finally, the last phase of this research identified a number of design guidelines for smartphone applications inclusive of PwP which were drawn upon the reflection on the process and the combination of the knowledge gathered through the execution of the three previous research phases (RQ4).

The following sections describe each of these phases in detail.

4 Literature review on Parkinson's symptoms

The first step of this research was to understand the characteristics of PD, to then hypothesise which of them could hinder PwP's interaction with smartphones. A review of medical literature, publications from patient associations, and other health-related websites allowed for the identification of the most common motor and non-motor symptoms of PD. These and the On/Off phenomenon, a specific characteristic of PD, are described below as found in the medical literature. Whenever available, testimonial excerpts from PwP, as extracted from patient associations and other health-related websites, were also included. These were researched to demystify the technical medical jargon and understand how and to what extent the symptoms are actually experienced and impact the daily life of PwP.

4.1 Motor symptoms

Bradykinesia, rest tremor, rigidity and postural and gait impairment are the most common symptoms of PD (see review by [29]) and constitute the cardinal features of a clinical syndrome called Parkinsonism. While each PwP experiences different symptoms, these cardinal features are usually present. Tremor for example, affects around 70% of the PwP [28] and freezing of gait, included in gait impairment, 47% [21].

Bradykinesia consists of a progressive slowness of movement speed and amplitude while performing sequential and simultaneous tasks [21,5]. The presence of this symptom can impact fine motor control tasks, such as: buttoning a shirt and using utensils [21]. Changes in facial expression, voice and handwriting are also documented [29].

> "What is going on inside your head is that you are thinking at a normal rate and your body is moving, at probably, one tenth of that rate. It's been like, you want to get a glass of water. Normally you would reach to pick up a glass of water and drink it. With Bradykinesia: I'm drinking a glass of water. The hand is going, going, going, still going, still going, still going... finally, you grasp the glass. And it's just very, very slow movement. Very extremely slow movement sometimes. Very frustrating cause your mind is saying: ok you want to drink, get it done, get it done, get it done. And your body is going: Oh I'm going in slow motion". Anonymous [48]

Rest tremor is an involuntary oscillating movement that occurs when the muscles are relaxed or supported by a surface [13]. Contrary to common belief, rest tremor may not affect the execution of fine motor tasks as it disappears or is attenuated when an action is started [21].

> "The tremor seems to be constant and sometimes it's quite vigorous, so vigorous that, you know, it'll shake my whole body. And if I'm trying to write, if I put anything on the table and my hands, left hand is on the table, it shakes the table. So that's one of the problems. But funnily enough it seems to be reduced if I'm working in the garden. I don't notice it quite as much." Keith [19]

Rigidity consists of an increased resistance to the passive movement of a limb [21] that occurs during the whole duration of the movement regardless of its speed [29]. The presence of rigidity is likely to affect fine motor tasks including turning round, getting up from a chair and even facial expressions [14]. In addition to making movement more difficult, stiffness is also responsible for pain [21].

> "This particular day I was using a hedge trimmer and I thought I had just pulled a muscle. My left arm felt stiff" Nicky [42]

Postural instability and gait impairment are also common, especially in more advanced phases of the disease [21]. PwP tend to adopt a stooped posture, with head and shoulders hanging forward, due to the loss of postural reflexes [21]. As the disease advances, gait becomes slower and unstable. Steps become smaller, and shuffle and turning becomes slow [29]. Freezing of gait is also common, especially in crowded or narrow spaces [13]. Festination, or the phenomenon of quickly walking a series of steps without being able to stop before colliding with an obstacle, can also happen from time to time [13,29].

> "Some days you can walk quickly. Other days you can hardly drag your feet around, and at best you have a shuffling gait. (...) The balance is not so good, especially when you have to stand for a while. To wear a badge that says "I am not drunk, I have Parkinson's' would be a good idea." Hanne [14]

4.2 Non-motor symptoms

Non-motor symptoms, although typical, tend to be underrecognized due to the absence of complaints by patients during their medical appointments [6]. These include autonomic sexual dysfunction, sensory abnormalities and cognitive or neurobehavioral disorders [53].

Sensory symptoms (olfactory dysfunction, pain, paresthesia, akathisia, oral pain and genital pain) are frequent in PwP, but are often not recognised as parkinsonian symptoms [21, 46, 25, 10].

Cognitive disorders are common. Neuropsychological investigations of PwD have shown specific impairments, even in the early stages of the disease [16], which include deficit of behavioural regulation in sorting or planning tasks, defective use of memory stores, and impaired manipulation of internal representation of visual-spatial stimuli [11].

Dementia[3] is increasingly recognized as an associated feature of PD in advanced ages and severe disease phases [27].

4.3 On/Off phenomenon

The On/Off phenomenon is an important characteristic of PD that appears only in medium to advanced phases of the disease. The PwP is said to be on the On phase when the medication is acting with great strength, and thus the patient shows less symptoms. On the Off phase, however, the medication stops being effective and the PwP might experience a severe impact on their autonomy.

As the disease progresses, Levodopa, the most common medication for the disease, is likely to be less effectively absorbed by the brain. This means that in the medium to later stages of the disease, patients can fluctuate between On and Off phases. The long-term intake of Levodopa is also likely to produce 'dyskinesias' (spasmodic movements, repetitive motions or lack of coordination), during the On phase. This is considered to be a side effect of having too much medication in the organism, which can occur in later phases of the condition [29].

5 Semi-structured interviews and observations

The literature review provided a list of symptoms that could potentially impact the interaction with the smartphone. However, the symptoms were described with technical jargon and insufficient detail to exactly understand how these could influence the actual interaction of PwP with a smartphone. With this in mind, an inquiring phase was considered to gather a more comprehensive understanding. Having considered interviewing PwP, this methodological decision was discarded due to the usually difficult access to end-users and the prioritization of the involvement of PwP in the usability experiments that for validity purposes required the participation of a wide number of PwP.

The authors then decided to conduct eight interviews with health professionals with extensive training and experience working with PwP: six neurologists, one physiotherapist, and one geriatrician. The selection of interviewees was of an opportunistic nature. Half of the participants were members of the REMPARK project consortium, and the other half were practitioners in the city of Porto, where the researchers were based. At this stage of the research, all professionals with a good practical understanding of the implications of PD in the life of PwP were considered adequate and could contribute to the understanding of the condition and how it was daily experienced by PD. The majority of the interviewees were neurologists because these are usually the clinical staff responsible, who then may or may not direct the PwP to another professional, for example, a physiotherapist.

The interviews turned out to be an optimal opportunity for understanding the issues of PwP. In complement to the interviews, two observations were held with two PwP showing their symptoms to their neurologist, as part of a simulated consultation, and dozens of online videos were visualized, to better understand how symptoms impacted the patients in practice. The observations informed the interviews and enabled a richer understanding of the symptoms. Notes about the observations were included in the analysis of the interviews.

The area of interest of the interviews was selected beforehand, as a result of the literature review. The

[3] Dementia is a neurodegenerative disorder that affects the brain, causing memory loss, reasoning and communication issues and other symptoms. Refer to [1] for a short summary on characteristics of the disease and how it affects one's life.

primary goal was to understand how the symptoms of the disease translated into daily difficulties. Four main areas were covered in the interviews:

- i) how PD changes and affects the life of PwP,
- ii) how PD affects motor and cognitive skills,
- iii) how do PwP interact with their mobile phones, and
- iv) what specific PD symptoms might affect the use of smartphones.

The interviews lasted between thirty minutes and one hour and were conducted in person (four) or over phone (four). All interviews were audio-recorded, and analysed by methods of Grounded Theory [8], such as open coding, axial coding, and selective coding. The analysis was performed in parallel with the interviews, adding new questions as they became relevant to the study. The interviews were coded by the third author and subsequently discussed with the first. The analysis was supported by [38], a qualitative data analysis computer software. The coding was performed directly on the audio recordings and was divided into three phases: open coding, axial coding and selective coding. During open coding, codes emerged naturally resulting into 36 different codes. Following open coding, axial coding was performed to organize the initial codes into clusters, based on their affinity. This resulted in 24 different codes (see Table 1). Selective coding was then applied to bring focus to the codes that could have had an impact on the smartphone usage. Table 1 shows, marked with an asterisk, the 15 codes selected. Furthermore, saturation of themes was achieved with eight interviews.

Some names of codes are similar to the terms found in medical literature. However, their use in this study is very different from the one found in the medical literature. The approach to creating the categories was very pragmatic, focusing on how the symptoms may actually affect the interaction with the smartphone. Even if the inquiry started very open, in search for different symptoms than those in the literature, the interviews did not lead into radically different symptoms.

5.1 Interviews results

Three main categories emerged from the analysis: i) Motor characteristics that may affect the interaction with the smartphone; ii) Cognitive characteristics that may affect the interaction with the smartphone; and iii) General characteristics to consider when designing for PwP. This section documents the different interview results (IR) under each category.

5.1.1 Motor characteristics of PD that may affect the interaction with the smartphone

The implications that PD motor symptoms may have on the interaction with smartphones are described under this category, each being henceforth labelled as an Interview Result (IR).

IR1: Bradikynesia can slow repetitive movements. Bradikynesia can make movements slow and progressively less wide. This may occur in gross as well as in fine motor movements. For example, as reported by one of the interviewees, PwP would not be able to hammer a nail. Each time they would lift the hammer, the distance to the nail would become narrower and narrower, eventually until the hammer just sat on top of the nail, without the person being able to carry out the task any longer. Similarly, repetitive fine motor movements, such as selecting a button multiple times are likely to become slow and difficult.

IR2: Rigidity makes interaction more imprecise and slower. Muscle rigidity makes muscles harder to move, thus lowering movement speed and dexterity, making regular tasks slower and harder to execute correctly.

IR3: Dyskinesias can make the interaction very difficult. When PwP have too much medication in their bodies, they can develop dyskinesias. These are responsible for uncontrollable involuntary movements that can render the interaction with the smartphone very difficult. In the words of an interviewee, having dyskinesia could be pictured as a person (without PD) standing "on a bus and trying to use a mobile phone", without being able to keep the arms still because of the movement of the bus.

IR4: PD may hinder speech. PD also affects the muscles responsible for speech. The interaction with the muscles for voice production may go unnoticed in early stages of PD, and as the condition progresses it may impact speech to the point that it becomes unintelligible. Therefore using common speech interfaces, may become impossible for PwP to use.

IR5: Some PwP may experience visual disabilities. PD is not associated with significant visual damage, however blurred and double vision can occur as a result of muscular incoordination. Decrease in colour and contrast discrimination also occurs. These limitations may be exacerbated when a PwP is also an older adult and the usual age-related changes may further affect

Table 1 Resulting axial coding scheme (24 codes). The selected codes are marked with an asterisk (15 codes).

Cluster Name	Code
On/Off Symptom Oscillation	• ***Contrast between On-Off phases** • ***Symptoms on Off** • ***Symptoms on On**
Disease progression effects	• Autonomy loss • Dementia • Disease progression effects • Multiple medication intakes
Possible consequences of PD motor symptoms on fine motor skills	• ***Difficult repetitive movements** • ***Known problems using a mobile phone or other device with buttons** • ***Rest tremor** • ***Dyskinesia effects** • ***Rigidity and loss of dexterity** • ***Slow movements with fingers**
Non-Motor symptoms associated with PD	• Apathy • Attention loss • Fatigue and depression • Pain • ***Planning problems** • ***Problems in vision**
General characterization of a PwP	• ***Asymmetric symptoms** • ***Bradykinesia effects** • ***Different groups of PD affected persons** • ***Major symptoms** • Lack of balance problems

her/his vision.

IR6: PwP are likely to use the phone while standing still or sitting. For a PwP, it may be dangerous to use a device while walking, said one interviewee, explaining that with ageing, people start losing their ability to multitask. This problem increases for PwP, as they develop postural instability as well. This is important when developing applications for PwP because having interactions that call for immediate response, such as an irritant alarm, may be dangerous.

IR7: The impact of PD hands' tremor is limited. Rest tremor is commonly associated with PD. According to one of the interviewees, this type of tremor mostly "disappears as they move their hands voluntarily". Therefore, tremor is not likely to affect fine motor skills.

5.1.2 Cognitive characteristics of PD that may affect the interaction with the smartphone

This section describes the implications that cognitive characteristics may have on the interaction with a smartphone. All interviewees suggested that cognitive issues are not the major problem in PD, they still reported some changes experienced by PwP.

IR8: Short-term memory loss is accentuated on PwP. PwP commonly experience short-term memory loss as part of the disease, which is mainly noticed when planning tasks, or when adjusting to a new medication. Furthermore, these problems coexist with the effect of age-related changes on the memory system.

IR9: Thought is slowed by PD. Slowness of thought is an age-related change. However, interviewees reported that PwP will experience slowness of though more regularly than people without the condition.

IR10: Depression and apathy are common in PD. Interviewees reported that many PwP exhibit some form of depression and apathy, sometimes even before the first motor symptoms appear, making these the first signs of a PD diagnosis. This means that PwP may not be as motivated to learn to use new technologies as others and may feel more frustrated or lost when facing novel situations.

IR11: Dementia cases are often observed on later stages of the disease. The first symptom is the appearance of complex visual hallucinations. As one interviewee said "as visual hallucinations start appearing we know that the patient is starting to become demented". Afterwards, cognitive degradation is clear, causing them to lose the ability of being functionally independent. According to one of the interviewees, the estimated prevalence of dementia in the overall population of PwP is 15%.

5.1.3 General characteristics of PD to consider when designing for PwP

This section outlines characteristics of PwP to consider when designing for these users. While these are not directly connected with motor or cognitive characteristics, as are the two previous sections, they provide important information that may be crucial when designing for these users.

IR12: Parkinson's disease symptoms significantly vary across different PwP. Interviewees highlighted the difficulty of building a typical representation of the PwP, due to the variability of symptoms. With this in mind, designs should be flexible enough to adapt to the characteristics of each person.

IR13: Symptoms vary between On and Off phases. As a result of the progression of the condition, many PwP experience the On and Off phenomenon. An individual can be fully functional on the On phase, and severely impaired while on Off. This translates into changes in the interaction with the smartphone. One interviewee referred, for example, that some patients would stop being able to write SMSs when entering the Off phase. Thus, when designing for PwP, one should consider the differences in abilities between On and Off, and perhaps even provide different interfaces for the different phases.

IR14: The disease progresses differently from person to person. It is difficult to find a progression pattern of PD. However, in general, the older the age of onset, the faster the disease progresses. Design flexibility should be kept in mind not only to adjust to different users, but also because a single user alone can experience a very noticeable progression over short periods of time.

IR15: Autonomy is gradually lost. At the beginning of the disease, PwP can lead their lives without major limitations, and as the disease progresses, they become less and less autonomous in pursuing basic daily activities. User interfaces should support these too.

The interview results somehow give an overly negative image of PwP, which may lead to think that disability in PwP is universal. This might be explained by the clinical mindset of the interviewed informants, who daily adjust treatments to deal with impairments. However, as the usability experiments will show, not everyone with PD faces all issues, and all of them to accute levels. Also, the ones that might do, may not experience them everyday or every time. Different PwP will encounter very specific challenges, which makes designing for PD especially difficult [36].

The results of the interviews complemented the information gathered in the literature review, completing RQ1 and RQ2. It was then important to assess to what extent the findings of the interviews affected the interaction of PwP with smartphones. For this reason, and building upon the findings of the interviews and the literature review, a series of usability experiments were designed; these are described in the next section.

6 Usability experiments

To measure the extent to which PD symptoms affected the interaction with the smartphone, usability experiments were created. Experiments used the within-group method [24] and tested four gestures: Tap, Swipe, Multipletap, and Drag. Tap and Swipe were chosen due to their heavy use on today's smartphones. Multiple-tap and Drag were chosen because they were adequate for building smartphone interfaces for medical questionnaires with scales, a requirement of the REMPARK project.

Thirty-nine PwP (17 females, 22 males) performed the usability experiments. Participants average age was 64 (median: 66; STD: 7.4) had been diagnosed as having PD since at least 10 years (median: 8; STD: 5.8). All participants took part of the experiment while on On phase. Regarding self-reported motor symptoms: 59% had tremor, 59% had rigidity, and 26% had dyskinesia. Some of them (13%) had undergone deep brain stimulation surgery. The recruitment was through two delegations of the Parkinson's disease patient association in Porto and Lisbon, as well as the Hospital of São João (Porto).

Before starting a test session with each participant, the facilitator presented himself and the project, explained the objectives of the test, and obtained written informed consent. The order of the experiments was: Tap, Swipe, Multiple-tap and Drag. While performing the experiments, the smartphone was placed on the table. Between experiments, participants were given the possibility to rest for as long as they felt needed. To facilitate participants' understanding of the experiments, both a video tutorial with visual instructions ('Learn' option of the test tool as described later) and a number of training prompts ('Training' option of the test tool as described later) were available in the smartphone used for the tests. These offered the participants an opportunity to practice the test situation without having their performance being measured. Only after watching the video tutorial and practising the tasks were participants' interactions measured by the application. In cases where neither strategies were clear enough to the participants, the facilitator demonstrated how to perform the test once again.

6.1 Test tool

The test tool consisted of four different experiments designed to measure the performance of the PwP with Tap, Swipe, Multiple-tap, and Drag gestures. This section presents the different test scenarios.

6.1.1 Tap

The Tap experiment was designed to determine the effect of PD on the Tap gesture, in particular the minimum size of target required and the minimum spacing to surrounding elements. In the test (See Figure 1) participants had to touch a square target that looked like an insect (Each target was a square which sides had the maximum height of the insect). The target appeared in different sizes, at different positions, and surrounded by distractions of different sizes. Test conditions are described in Table 2.

The sizes of targets followed previous work of Leitão and Silva [26], who defined the size of their target sizes with reference to the (larger) average size of a human fingerpad, 10mm to 14mm, as identified by Dandekar et al. [9]. To the largest fingerpad average size, Leitão and Silva [26] then defined two larger and two smaller target sizes. This study used the same sizes: 21mm, 17.5mm, 14mm, 10.5mm and 7mm.

The experiment first displays larger targets and then smaller ones. The distractors are also at a longer distance in the beginning and become closer subsequently. The insects appear in three positions of an invisible equilateral triangle, which ensures that subsequent targets appear always at the same distance, and thus allow reaction time to be measured. Moreover, the sequence of target positions was randomized so participants could not easily guess where the next target was going to appear.

During the experiment three variables were logged: i) reaction time; ii) number of touches until target is reached; and iii) coordinates of each touch.

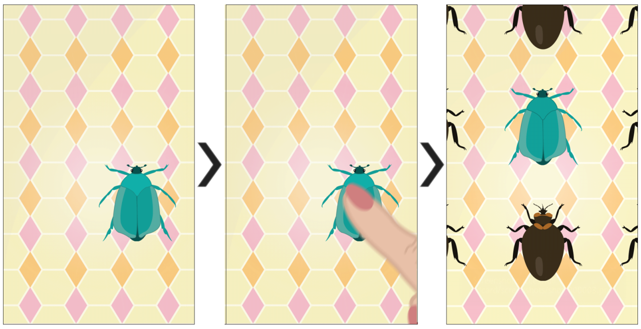

Fig. 1 Sequence of interaction of the Tap experiment. First, the participant sees the target (left). Then taps it (middle). And finally, the next target appears in a different position and surrounded by different distractions (right).

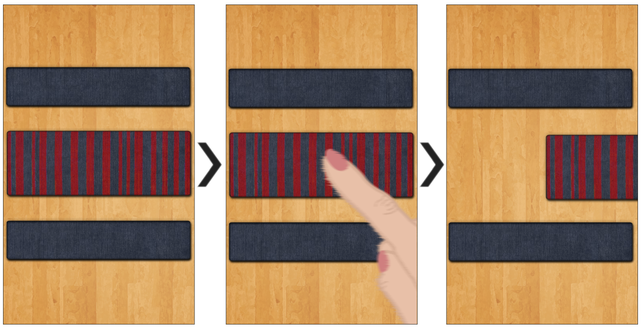

Fig. 2 Sequence of interaction of the Swipe experiment. First, the participant sees the target (left). Then s/he swipes it (middle). Target disappears with an animation (right) bringing the next target in a different position and surrounded by different distractions.

6.1.2 Swipe

The Swipe experiment was designed to determine the effect of PD on the Swipe gesture, in particular the minimum height required for the target and the minimum speed for recognizing the gesture. The test tool consisted of the participant having to slide a rug with various spaces on the screen (see Figure 2) and again used the same sizes as Leitão and Silva [26].

Similar to the Tap experiment, the Swipe test displays different rug heights and distances between the distractions sequentially from bigger to smaller sizes. In this case the distractions consisted of two different rugs appearing above and below at different positions. Table 3 displays the test conditions.

Table 2 Test conditions of the Tap experiment.

Target sizes	21.0 mm	17.5 mm	14.0 mm	10.5 mm	7.0 mm
Spacing to surrounding elements	(single target)	10.5 mm	7.0 mm	3.5 mm	0 mm
Test scenarios	15 unlogged sessions to gain familiarity with the test + 75 (5 Sizes x 5 Spaces x 3 Positions) test situations				

The sequence of the positions was random since otherwise it would be too easy to guess the position of the next rug on the screen. Additionally, no swipe's trigger velocity was considered; a swipe gesture was defined as a gesture from left to right beginning above the rug.

During the experiment five variables were logged: i) reaction time; ii) participant taps per target; iii) coordinates of each touch; iv) distance per gesture; v) gesture duration.

6.1.3 Multiple-tap

This test was designed to measure how quickly a PwP was able to perform multiple touches repeatedly on the same button. The test (See Figure 3) included an empty scaled pipette drawn on the screen and two buttons (arrow up and arrow down); the goal was to control the water level, by filling the pipette by touching the arrow up until the water reached the green mark drawn on it. Additionally, to correctly assess the number of taps, a 'next' button was added to proceed to the following test condition. This button would appear when the participant had the water level on the green bar and disappeared when the mark was overpassed. In order to get the water level back to the green bar, the participant would have to tap the arrow down button to decrease the water level. Table 4 details the experiment.

During the experiment three variables were logged: i) completion task time; ii) time to reach the mark; and iii) number of touches for each test. The task completion time considered the time between the first touch on an arrow button until the time of the last touch on another arrow button. The time required to touch the 'next' button was not included in the measurement. For example, considering a test in which the participant makes no mistakes to get the water to level three, the time measured would be the time difference between the first and the third touch. If the participant touched the 'up arrow' button more times than needed, thus surpassing level three, the time measured would include the corrective touches.

The multiple-tap test was included in the experiments to understand if it could be used to implement medical questionnaires with scales. The following section shows the alternative to using this gesture.

Table 4 Test conditions of the Multiple-tap experiment.

Scale	1 to 10
Marks on water levels	2 to 10
Test scenarios	4 unlogged sessions to gain familiarity with the test + 9 marks test situations

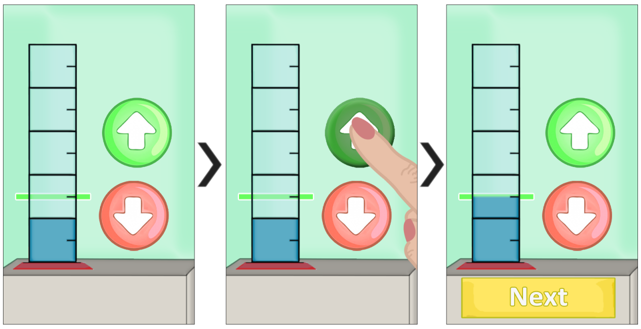

Fig. 3 Sequence of interaction of the Multiple-tap experiment. First, the participant sees the pipette filled with two levels of water (left). Then s/he increases one water level by pressing the up arrow (middle). Finally, the participant reaches the desired level, marked by a green bar, and the button 'next' appears (right). Clicking the 'next' button, brings another repetitive tap experiment with a different objective and level of water.

6.1.4 Drag

This test was designed to check if PwP could drag an element on the screen with precision. The test tool consisted of a simple seek bar with a ball as a selector, the corresponding scale was shown above it, and a boy was displayed in an objective mark on that scale. The participant had to drag the ball to the boy. As the test progressed, the scale and the mark's position changed. The ball moves smoothly, without jumping, while gradually changing the mark' values. Figure 4 shows a screen sequence that exemplifies this test and Table 5 displays the test conditions.

During the experiment one variable was logged: completion task time.

6.2 Technical implementation details

The experiments were developed for the Android platform and designed to run on the 'Samsung Google Nexus

Table 3 Test conditions of the Swipe experiment.

Target sizes	21.0 mm	17.5 mm	14.0 mm	10.5 mm	7.0 mm
Spacing to surrounding elements	(single target)	10.5 mm	7.0 mm	3.5 mm	0 mm
Test scenarios	15 unlogged sessions to gain familiarity with the test + 75 (5 Sizes x 5 Spaces x 3 Positions) test situations				

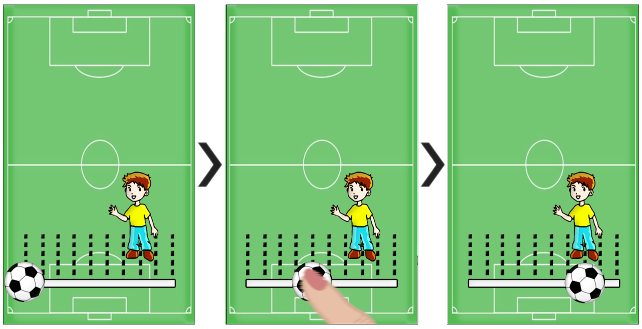

Fig. 4 Sequence of interaction of the Drag experiment. First, the participant sees the ball (moveable target) and the boy (static target) (left). Then the participant moves the ball to the boy by dragging it (middle). Removes the finger from the screen when finished (right) which then brings another drag experiment with the ball in a different place and a different scale.

Table 5 Test conditions of the Drag experiment.

Scales	1 to 3	1 to 5	1 to 10
Marks on football field	1 to 3	1 to 5	1 to 10
Distance between marks on football field	21.1mm	10.5mm	4.7mm
Test scenarios	4 unlogged sessions to gain familiarity with the test + 15 marks (2 + 4 + 9) test situations		

S' since this was the smartphone selected by the REMPARK project. This smartphone has a 4-inch capacitive touchscreen, supports 480x800 px resolution, and features 123.9x63x10.9 mm dimensions.

Each experiment was developed as a separate (Android) Activity that was called from a common menu that listed the four experiments. This menu offered quick access to the experiments, and, if needed, allowed the flexibility for the participant to rest before starting the next experiment. Under the button of each menu option, three other options were available, including: 'Learn', 'Training' and 'Play'. Both 'Learn' and 'Training' did not log the results, as they were meant to familiarize users with the test situation. 'Play' on the other hand, logged the results for each participant. The 'Learn' option consisted of a video demonstrating the actions of the upcoming experiment. Whenever a video was ignored by the participants, the facilitator would demonstrate those same actions. The 'Training' option consisted, for the tap and swipe tests, of performing three touches for the largest targets for five different spacings and, for the multiple-tap and drag, of performing three fills and three drags. The 'Play' option consisted of the actual test situation.

Each log entry had the participant id, condition and the data recorded for each experiment. Logs were parsed, using a custom Ruby script, in the Microsoft XLS format, so that it could be analysed on both Microsoft Excel (v14.0) and SPSS Statistics (v20.0.1). The Ruby script parsed all log files (one log file for each test of each participant), applied the specified formulas to calculate the abstract variables (e.g. time intervals, click counts, etc), and saved all logs into a single XLS file, with one sheet for each experiment. From there, the above-mentioned software packages could be used for the analysis. The following section presents the results of the analysis with ANOVA [45]. The modular nature of the setup enabled the analysis of the test data as it became available, and made it easy to add new variables as they were required.

6.3 Results

This section presents the results grouped by experiment (Tap, Swipe, Multiple-tap and Drag). In the end of the Section, Multiple-tap and the Drag gestures are compared.

6.3.1 Tap

This section presents the results of the Tap experiment described in Section 6.1.1 The analysis looks at the effect of button size and distance to surrounding elements on touch efficacy, by measuring touch accuracy and reaction time.

Mean touch accuracy. Accuracy was calculated based on the number of taps on target divided by the number of insects plus missed targets. Considering this, the mean accuracy was above 97% in three out of five button sizes and above 93% in four out of five (see Fig-

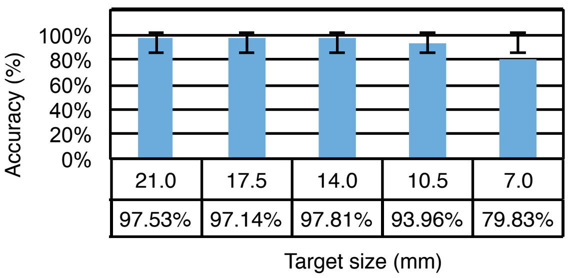

Fig. 5 Mean accuracy by button size for the Tap experiment.

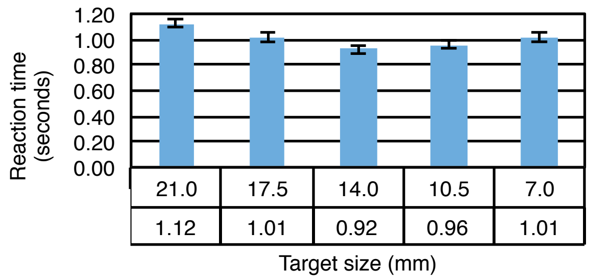

Fig. 7 Mean reaction time by button size for the Tap experiment.

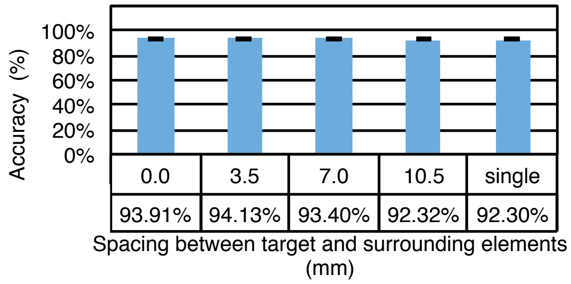

Fig. 6 Mean accuracy by spacing between target and surrounding elements for the Tap experiment.

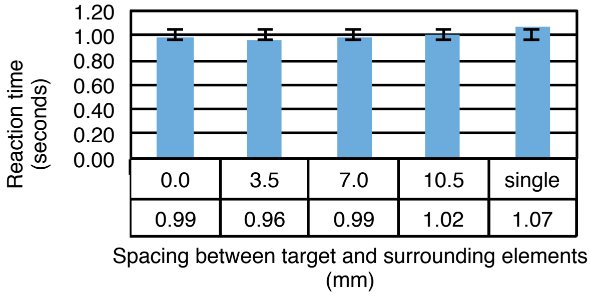

Fig. 8 Mean reaction time by spacing between target and surrounding elements for the Tap experiment.

ure 5). Results show that mean accuracy tends to decrease with button size, especially in the two smaller sizes, however the 14.0 mm button has a higher mean than the 17.5 and 21.0 mm targets. This may be attributed to training, since the test presented buttons from greater to smaller size. Furthermore, the effect of the button size test was significant F(1.165,62)=29.511, p=.0001.

Regarding the spacing to surrounding elements, there is a slight increase of the mean accuracy as spacing between target and surrounding elements is reduced (see Figure 6), however this difference is very small (max 1.83%). Such a small difference indicates that there is no great difference among different spacing alternatives between target and surrounding elements. In the same direction, the ANOVA analysis shows that this effect was not significant F(3.13,128)=1.430, p=.236.

Mean reaction time. The mean reaction time did not change significantly between the different button sizes (see Figure 7). There is a slightly higher reaction time for larger buttons that decreases until the 14.0 mm button, and increases again for the smaller button sizes. This can be due to a learning effect, that takes place as users consistently get more used to tapping (the reaction times are lowering), until the target is too difficult to hit with precision. Moreover, these results have shown to be significant F(2.35,89)=4.754, p=.008.

When the spacing between target and surrounding elements decreased, the mean reaction times also decrease (see Figure 7), with the exception of the 0.0 mm spacing. However, this variation (1.07-0.96=0.11) is very small and was shown not to be significant F(3.36, 128)=2.023, p=.107.

Summary and discussion. This experiment has shown that the target size influences the accuracy of Tap while the spacing to surrounding elements does not. Participants achieved an accuracy of 97% or more with square targets of 14mm or more of side, with targets of 14mm offering the best accuracy rates, that is an accuracy of 98%. Given a situation in which screen space is limited, 10.5mm targets can also be used offering an accuracy of 94%. The spacing to surrounding elements does not seem to affect the accuracy of Tap (differences of accuracy equal or less than 2%). Moreover, when looking at the mean accuracy rate and the mean reaction time, the 14mm target size is the one that offers the best accuracy, strengthening the case of the 14mm when compared to others.

6.3.2 Swipe

This section presents the results of the Swipe experiment described in Section 6.1.2. The analysis focused on the effect of Swipe target height and distance to surrounding elements on swipe accuracy, by measuring

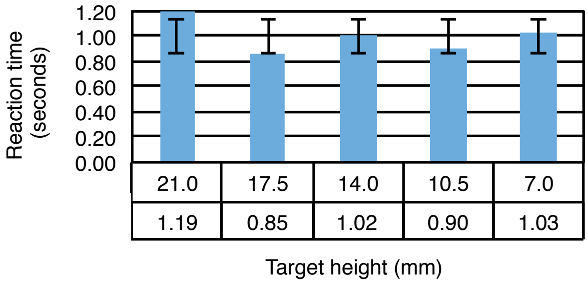

Fig. 9 Mean reaction time by rug height for the Swipe experiment.

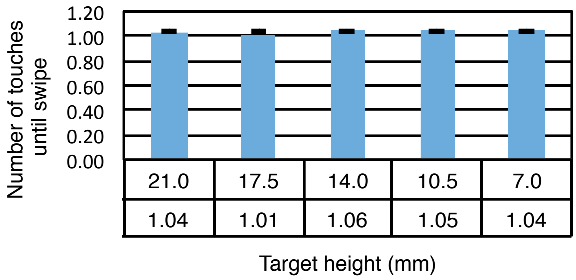

Fig. 11 Mean number of touches required to perform a successful swipe by target height for the Swipe experiment.

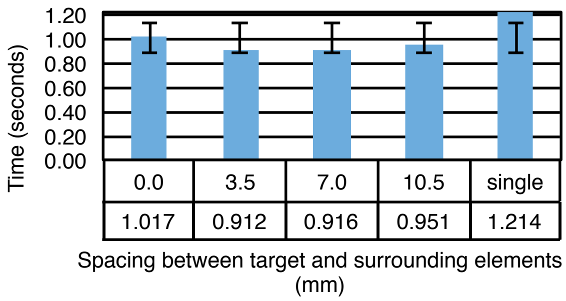

Fig. 10 Mean reaction time by spacing between target and surrounding elements for the Swipe experiment.

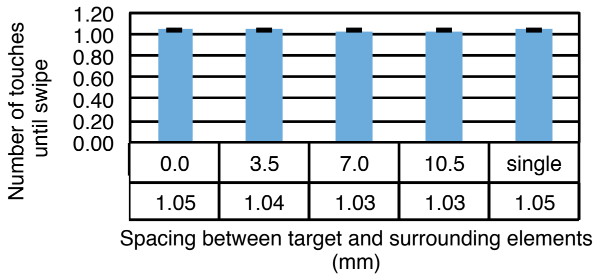

Fig. 12 Mean number of touches required to perform a successful swipe by spacing between target and surrounding elements for the Swipe experiment.

reaction time, number of touches needed per swipe and speed of swipe.

Mean reaction time. The best mean reaction time is observed with the 17.5mm swipe target size, however reaction times fluctuate for the different target heights without a particular pattern (see Figure 9). Also, the effect of the target height was not significant F (2.076,79)=2.396, p=.096.

With the exception of the first target, there is a slight decrease in the mean reaction time as the spacing between target and surrounding elements decreases (see Figure 10). This behaviour trend was significant F (2.057,78)=5.299, p=.006.

Mean number of touches. While participants were marginally faster with the 17.5mm size, the average number of touches to perform a successful swipe did not vary significantly with target height (see Figure 11). The non-significant results (F (1.177,107)=1.177, p=.321) suggest there might be no effect related to the target height. The average number of touches did not vary significantly with different spacing between target and surrounding elements either (see Figure 12). Finally, the significance analysis also showed non-significant results (F(3.022,115)=0.838, p=.476), suggesting there might be no effect related to spacing.

Swipe speed. The different target heights and spacing between target and surrounding elements did not contribute to a great variation on gesture speed. The effect of the target height was not significant F (2.130,80)=3.879, p=.022 but a small decrease in speed being observed between the higher target's height and the lower target's height (see Figure 13) and being fastest with the 14mm target height. It is worth mentioning that during the tests some participants performed swipe movements very slowly. This suggests that applications expecting fast swipes may not appropriate for PwP. To identify the speed at which the participants would be able to swipe, an analysis of the speed was performed considering each participant individually (see Table 6). The analysis showed that $\tilde{9}$5% of participants made swipes faster than 24mm/s, while only 87% were over 64mm/s.

Summary and discussion. Results show that PwP are able to perform swipes and that no significant correlation was found between target height and spacing between target and surrounding elements for the swipe gesture.

The analysis of the swipe speed showed that distinct participants swipe at very different speeds. To support around 95% of participants, the swipe should accept

Table 6 Percentage of participants that perform a swipe gesture at a given threshold speed.

Speed threshold (mm/s)	>24	>29	>34	>39	>44	>49	>54	>59	>64
Participants above the threshold (%)	94.87	92.31	92.31	92.31	92.31	92.31	89.74	89.74	87.18

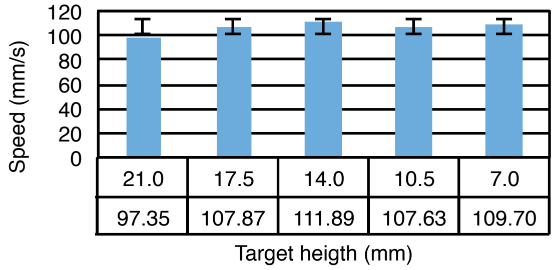

Fig. 13 Mean speed of swipe gesture by target height for the Swipe experiment.

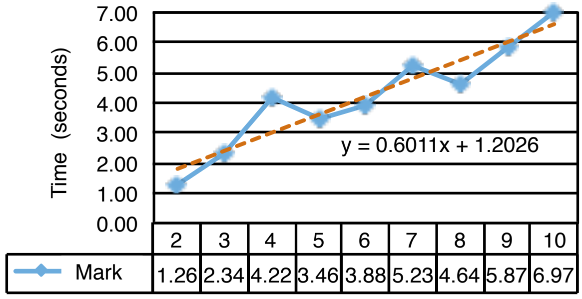

Fig. 14 Mean time to perform n number of touches repetitively for the Multiple-tap experiment.

movements of 24mm/s. It would have been interesting to compare this value with the ones of implementations on today's smartphones; this was not done because manufactors do not share this information. An interesting topic for future research would be to investigate if applications could detect dyskinesias, by detecting unusually fast gestures.

6.3.3 Multiple-tap

This section presents the results of the Multiple-tap experiment described in Section 6.1.3. This test aims to understand the ability and effort of performing successive multiple taps, by measuring the time to perform a predefined number of ten taps. Moreover, in order to compare it with the Drag experiment, task completion time was also recorded.

Mean time to reach a mark. All participants were able to perform the 10 predefined taps. There is a linear increase of task time as the number of touches required increases (see Figure 14). A simple linear regression shows that the slope is 0.601, meaning that, on average, a unit increase in the number of touches will be responsible for a time increase of 0.601 seconds. The results were significant, $F(3.01,114) = 8.108$, $p=.001$.

An analysis was also conducted to understand if there would be any slowing between taps. The results showed a difference of 159ms between two and ten multiple taps (see Table 7) .

Summary and discussion. This experiment shows that participants can perform successive taps with no significant reduction in speed, at least until the tenth tap. These results challenge the data from the interviews that anticipated PwP would be strongly affected by bradykinesia. This might be the case for this particular set of participants a result related to the fact that participants performed the tests while in the On phase. Future work, should include more tests with participants doing the tests also while on Off phase to clarify this aspect.

6.3.4 Drag

This section presents the results of the Drag experiment described in Section 6.1.4. The analysis looks at the effort of performing a drag by measuring the time to reach a desired mark.

Time to reach the desired mark. There was no significant difference between the task completion time of dragging the ball to a specific position on different scales (see Figure 15). The 3- and 10-element scales had a mean completion time of 4s while the 5-element scale had a mean completion time of 3.5s. This small difference was unanticipated and might be related with the training effect since the scales were presented sequentially in ascending order. The effect of scales in completion times was significant $F(1.9,73) = 4.112$, $p=.022$.

Summary and discussion. This experiment has shown that participants were able to drag objects with precision over a scale of at least 10 elements. Participants were slow to reach their goal (taking on average four seconds), but were able to use the scale without further adaptations.

Table 7 Mean time between taps for each number of repetitive taps.

Number of repetitive taps	2	3	4	5	6	7	8	9	10
Average time between taps (ms)	476	655	768	600	589	663	533	569	635

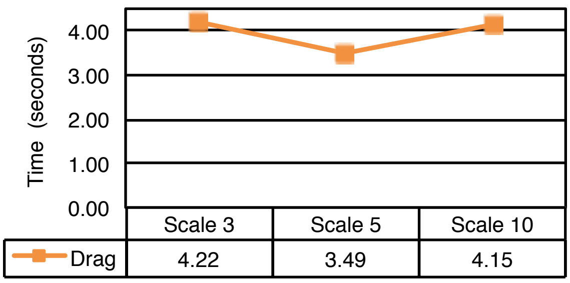

Fig. 15 Mean completion task time by scale for the Drag experiment.

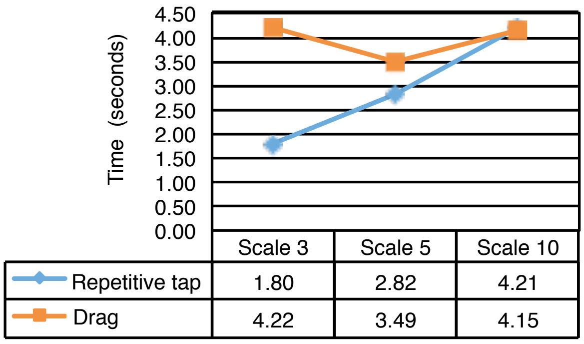

Fig. 16 Mean completion task time by scale comparing Drag with Multiple-tap.

Regarding the distance between dragging elements, the experiment showed that 4.7mm is enough for the task to be successful.

6.3.5 Multiple-tap vs Drag

Besides the individual analysis of the gestures, Multiple-tap and Drag were compared. The two gestures were compared in three categories: scale three (1-2 marks), scale five (1-4 marks), and scale 10 (1-9 marks). These categories do not allow for the comparison for each mark increase, but give a better understanding of how the gestures perform against each other. The multiple-tap gesture has shown the best overall performance (see Figure 16), being the fastest for all scales. While drag also showed equivalent results for the last scale, participants exhibited more frustration when performing the test with the drag.

Summary and discussion. Participants exhibited a better performance with multiple taps. This means that up to 10 elements, multiple-tap is the best option to input data in scales.

7 User Interface Design Guidelines for Smartphone Applications for PwP

By reflecting on the findings of this study, 12 user interface design guidelines (DG) were developed for creating smartphone applications for PwP. Those guidelines are grouped in two categories: i) Touch interaction and ii) Information display. Each guideline references the interview result code (IRn) or the number of the section describing the usability experiment that grounds the guideline. Whenever appropriate they are also discussed in regards to other relevant literature.

7.1 Touch interaction

DG1 - Use tap targets with 14mm of side. The results of the usability experiments (See Section 6.3.1) show that participants were most accurate with targets of 14mm side (97.81%). Similar accuracy rates (>97%) were also achieved with targets of 17.5mm and 21mm, so 14+mm target sizes should be used for tap gestures. For situations in which screen space is limited, targets of 10.5mm are also a possible alternative given an accuracy of 94% is acceptable. Smaller targets (e.g. 7mm) perform much worse (<80%). The recommendation of using targets with 14mm of side aligns with the proposed target size for older people as identified by [26]. This may indicate that PwP do not require larger targets than older adults. While participants did not require 20mm of target side, as recommended for people with upper limb motor impairments [12], this size also offered good accuracy. The difference in the results could reside in the use of smartphones instead of kiosk screens in the study [12]. However, when comparing recommended target sizes for mainstream users (7-10mm) [40,41,2,3,52], PwP do require larger target sizes to achieve optimal performance, backing up the intuition from [30].

DG2 - Use the swipe gesture, preferably without activation speed. According to the results of the usability experiments reported in Section 6.3.2, participants were able to swipe accurately on the touchscreen under all conditions tested. Most participants (˜95%) made the swipes at a 24mm/s speed or more, so this speed should be supported by smartphone user interfaces for PwP. Alternatively, the activation speed of the gesture can be removed to accommodate for PwP. Findings contrast with previous work on older adults that suggested a target of 17.5mm [26] was required for best performance with swipe gestures, indicating that unlike older people, PwP do not have special requirements regarding target size for swipe gestures. Findings also contrast with the results from Trewin et al. [47] who reported that some people with upper limb impairments had problems with performing the swipe gesture.

DG3 - Employ controls that use multiple-taps. As detailed in Section 6.3.3, participants were not significantly affected by bradykinesia in the Multiple-tap test. This indicates that multiple-taps are adequate for user interfaces for PwP at least until the 10th tap. Nonetheless, this gesture should be used conservatively since successive taps may tire the users and discourage them from using the interface.

DG4 - Use drag gesture with parsimony. As reported in Section 6.3.4, participants were able to perform drags in all sensitive scales tested (with elements spaced by 4.7mm) in about 4 seconds; this indicates that drag gestures can be used on user interfaces for PwP. Still, some participants manifested some frustration while performing the test; this discomfort should not be ignored meaning drag gestures should be used with parsimony.

DG5 - Prefer multiple-tap over drag. Both multiple-tap and drag produced good results in the usability experiments we conducted (see Section 6.3.5), which makes both gestures appropriate choices for designing user interfaces for PwP. However, the Multiple-tap performs better until the 10th tap (maximum limit of taps considered in our test), therefore it should be preferred over drag.

DG6 - Adapt interfaces to the momentary characteristics of the user. According to the literature and interviews, PwP are likely to experience fluctuations in the intensity of their symptoms at different times (see IR12). For this reason, whenever possible, smartphones should monitor these differences in touch performance, for example, by tracking selection errors or measuring the time between clicks. Then, applications will be able to optimize the interaction to the current situation of the user.

7.2 Information display

DG7 - Use high contrast coloured elements. PD can impact vision, limiting the ability of distinguishing elements with low contrast (see IR5), therefore high contrast user interface elements should be preferred. This guideline aligns with previous work on touchscreen interfaces for PwP [30], as well as with general user interface design guidelines for older people [23,15,37]. Testing multiple levels of contrast is recommended to ensure interfaces are usable, until studies have more systematically evaluated different contrast levels with PwP.

DG8 - Select the information to display carefully. As reported in the literature [16], short-term memory loss is a common symptom of PD, which can easily overwhelm users if too much information is displayed. Therefore it is advisable to carefully choose the information to display. Previous work focusing on older people [23,37] suggested the same insight, however as the interview results suggested memory loss is especially aggravated by PD (see IR8). The amount of information that can be displayed will depend on each case and should be evaluated through usability tests.

DG9 - Provide clear information of current location at all times. Short-term memory loss and slowness of thought slow down the interaction with the smartphone. Having the current location displayed will remind users of what they want to achieve, and will quickly inform them in case they select the wrong target. Previous work has recommended making the current location clear for older people [23,37], however memory loss and slowness of thought of PD make it especially relevant for PwP. See IR8 and IR9.

DG10 - Avoid time dependent controls. PwP experience movement speed reduction, especially while on Off phase. This means that asking a PwP to answer, for example, a dialogue displayed within a few seconds, is likely to be a difficult and stressful task. These controls may hinder interaction and cause extreme frustration, and may ultimately lead to abondonment of the technology. For these reasons time limits should be avoided. See IR1 and IR2.

DG11 - Prefer multiple modalities over a single interaction medium. PD can impact both vision and speech, in ways that can hinder the interaction with the smartphone. One way of preventing this issue is to use multiple modality for the same control. For example, by using both visual and voice interface commands, applications will remain usable by PwP for a longer period, overcoming the potential loss in one of the modalities. See IR4 and IR5.

DG12 - Consider smartphone design guidelines for older adults. In 96% of the cases, PwP are diagnosed after the age of 50 [49]. This means that besides PD symptoms, a significant percentage of PwP will also experience age-related changes. For this reason, when designing for PwP, user interface design principles for older people should also be carefully considered (see e.g. [23, 15, 37, 44]). Furthermore, as IR5 concludes, PD may aggravate some symptoms of older age.

8 Discussion and limitations of this study

This section analyses and discusses the methodology and results of this study. It also highlights aspects related to the participants of the interviews and the usability experiments. Finally, it shares some reflections on how to approach the design of user interfaces inclusive of PwP.

8.1 Methodological approach

Despite complex and elaborated, the methodological approach taken in the context of this research is solid and thoroughly described. This allows for its replicability by other researchers interested in furthering the research and complementing the findings. The methodology mainly consisted of four phases: i) Literature review on Parkinson's Symptoms, ii) Semi-structured interviews and observations, iii) Usability experiments, and iv) User interface design guidelines for smartphone applications for PwP. Each of these phases contributed with significant input to comprehensively grasp the subject of the research.

8.1.1 Literature review on Parkinson's Symptoms

The literature review considered conventional medical sources, as well as patient associations and other health-related websites. All sources described the symptoms of the PD, and while the medical literature was concerned with the technical details of the symptoms, patient associations and health-related websites focused much more on implications of PD symptoms in the life of PwP. Gathering information from both perspectives was crucial to get a holistic understanding of the condition. This approach is appropriate and required when designing for special user populations who design teams do not fully understand.

8.1.2 Semi-structured interviews and observations

The interviews and observations arose in this study as a way to bring clarity and comprehension to the researchers on how, in a practical sense, PD affects the interaction with smartphones and impacts the daily - tasks and -life of PwP. While the best person to describe the personal impact of a symptom is the one who experiences it, the authors opted for involving the PwP only in the usability experiments, due to difficulties in recruiting participants. However, interviews were held with the next most knowledgeable experts in the disease - health professionals - who through their answers and suggestions of observations allowed us to make sense of the problems described in the technical literature.

Interviewees were recruited via the REMPARK project partners and through personal contacts. Including the project partners was useful not only to ensure that the vision of the project members was considered, but also because this way the project partners also understood the process followed by the authors. Including interviewees that were not part of the project brought a mix of perspectives that would have not been possible to obtain otherwise.

The analysis of the interviews relied on Grounded Theory methods. This approach was particularly useful to enable focus, comparison, and an iterative analysis. The focus was improved due to the systematic coding and memo-writing strategies. Constant comparisons between codes, interviewees, and literature were also beneficial in shaping the research. Performing the analysis while conducting the interviews was particularly useful as important themes, such as the effect of dyskinesia, only became relevant after some interviews. The account produced opened new perspectives and shaped the usability experiments included in this work.

8.1.3 Usability experiments

The usability experiments assessed the quality of the interaction of PwP with four different gestures: Tap, Swipe, Multiple-tap, and Drag. Whilst the study of these four gestures significantly advances the area of designing smartphone user interfaces for PwP, in the future, it would be interesting to investigate the impact of PD on the execution of other gestures, such as pinch, spread, and touch and hold.

The experiments were explicitly designed to decrease or eliminate any effect related to participants' experience with touchscreen-based devices. Demonstration videos were provided ('Learn' mode in test tool) and so was the possibility of acquiring experience ('Training' mode in test tool) before starting to log the results. The 'Learn' and 'Training' modes intended to make participants comfortable with the gestures and remove any initial difficulties. However, in the Tap, Swipe, and Drag experiments, a learning effect seemed to have taken place. In these tests, despite being theoretically easier, the first test conditions had longer reaction times, with participants becoming faster as they went through the experiment. Given a learning effect did take place, its interference was not critical to the results because accuracy was not affected. However, in the future, and given that measuring the reaction times accurately is crucial, test scenarios should offer the possibility for even more training. Additionally, precise reaction times need to be collected. This can be achieved, for example, by requiring the participant to touch an area of the screen before touching the next target or executing the next action.

The results of the usability experiment do offer validity. The results of experiments performed for Tap were significant both regarding accuracy (p=.0001) and reaction times (p=.008). These results are also in line with previous work (see Section 2, 7). For the Swipe, despite the size and spacing being irrelevant, our results shown that to accommodate 95% of the participants' swipes should accept movements of 24mm/s. Results were also significant for the Multiple-tap and Drag gestures. However the increased frustration expressed by the participants with the Drag, indicates that Multiple-tap is more comfortable to perform than Drag.

8.1.4 Participants sample used in the usability experiments

A generous sample of 39 voluntary PwP participated in the usability experiments. Participants were recruited opportunistically, regardless of their symptoms and years of disease onset. This does not guarantee that the individuals are representative of the PwP, since PD symptoms are not homogeneous, and fluctuations are common. However, it does reduce the influence in the recruitment process.

From the recruited participants, all participated in the tests while on the On phase, that is when the participants were more in control of their bodies. Arguably, the tests could have been repeated with the same patients while on Off phase in order to compare the results. However, the interviews suggested that a significant discomfort would be induced on patients by doing so. Moreover, the clinical partners of the REMPARK project argued that in most cases, a PwP on Off phase, would not be able to use a smartphone at all. For these reasons, tests with PwP on Off phase were not conducted, as the generated discomfort would not justify the extra information that would be gathered. Still, this may be worth exploring in future research.

8.1.5 User Interface design guidelines for smartphone applications for PwP

The guidelines proposed by this research have not yet been applied to user interfaces for PwP with the purpose of evaluating their efficacy. In some instances, the guidelines elicited are also vague (e.g. regarding contrast or how to deal with symptoms fluctuations). However, these guidelines emerged as an outcome of a careful consideration for the results of the literature review, interviews and observations, and usability experiments and as a consequence of a thorough reflection on the research process and the learning and experience obtained through it. This makes them solid enough and ready to be shared with other researchers and practitioners designing smartphone applications for PwP.

While the inclusion of guidelines that specifically focus on older adults, such as DG 12, may appear irrelevant, such a guideline ought to be included. Less experienced designers may not be aware of the high incidence of older adults among PwP, or may simply forget to take careful consideration for them, once they are not specifically included in a list.

8.2 Critical reflection and the need for a humane and inclusive design perspective

It is tempting to characterize PD purely as a disabling condition. This happened with some the participants interviewed, probably as a result of their training and experience in locating and addressing alarming issues. However, as often stated in this work, PwP do not experience all symptoms of PD and probably not in their most serious state. Also, besides their condition, PwP are humans who resiliently cope, learn, and adapt to their limitations, and are often able to achieve a positive coexistence with PD, living normally and independently for many years after diagnosis. Technology and design can play a crucial role in enabling PwP to live better lives for longer. It is true that PD is incredibly complex and manifests differently in different people and at different stages of the disease. This means that designing for PwP is exceedingly complex and that designers need to be proactive in developing more dynamic and responsive systems that are meant for humans who are not downright incapable. On the contrary, as some usability experiments have shown, participants were much more capable than they would have been expected to be, based on the interview results. This is the case, for example, in regards to the ability to perform multiple taps. It is then the role of researchers and practitioners, specially in design, to make a positive intervention that ensures technology is effectively an enabler and not a mere reminder of a disabling condition.

9 Conclusions and future work

This study focused on understanding how PD affected the interaction of PwP with smartphones. Its results can be taken up by researchers and practitioners alike designing for PwP. Previous work had investigated the interaction of PwP with touchscreen interfaces, however the performance of touch gestures on smartphones had not been systematically evaluated, neither had the reflection on the research process been used to produce guidelines that can support the future work of others. This paper furthers the research in this area, by contributing with: i) a documented list of the symptoms that may directly affect the interaction of PwP with smartphones; ii) a set of experimental results obtained through usability experiments assessing PwP's execution of Tap, Swipe, Multiple-Tap, and Drag gestures ; and iii) 12 user interface design guidelines for smartphone applications targeted at PwP. This paper also opens a number of opportunities for future research.

9.1 Lessons learned

The literature review provided initial insights on the symptoms of PD, and on the subset of issues that could impact the interaction of PwP with smartphones. This information was then complemented with observations and interviews with healthcare specialists. This enabled an effective understanding of how symptoms were experienced by PwD on their daily lives. It is important to consider aspects such as bradykinesia, muscle rigidity, dyskinesia, tremors, use of speech, the possibility of depression or dementia, and the variations that occur between On and Off phases.

The usability experiments showed that PwP can successfully perform the four gestures evaluated by this study. However, taps need large targets (of 14+mm for 97+% accuracy), swipes should not use activation speed, and using Multiple-tap is more comfortable and preferable to using Drag.

Drawing upon the above research phases, 12 guidelines for designing smartphone user interfaces for PwP emerged, relating to touch interaction and information display:

- DG1 - Use tap targets with 14mm of side;
- DG2 - Use the swipe gesture, preferably without activation speed;
- DG3 - Employ controls that use multiple-taps;
- DG4 - Use drag gesture with parsimony;
- DG5 - Prefer multiple-tap over drag;
- DG6 - Adapt interfaces to the momentary characteristics of the user;
- DG7 - Use high contrast coloured elements;
- DG8 - Select the information to display carefully;
- DG9 - Provide clear information of current location at all times;
- DG10 - Avoid time dependent controls;
- DG11 - Prefer multi-modality over a single interaction medium;
- DG12 - Consider smartphone design guidelines for older adults.

The different research phases also showed that PwP are very different from each other and experience symptoms differently through their day and as their condition progresses. This indicates that it is not possible to use a 'one size fits all' approach.

9.2 Future work

This work opens up a number of different lines for future work. Some of the lines of work relate to further operationalising the guidelines suggested, while other concern with expanding the study to different test situations.

Further operationalising the guidelines emerging from this study. Building upon the findings, it would be interesting to evaluate, for example, how much contrast PwP need between the different interface elements. While medical literature, interview informants, and previous touchscreen studies, referred that high contrast was required for PwP, it is not possible at this point to determine exactly how much contrast would be enough. Conducting this work will provide designers with necessary information to create more appropriate user interfaces for PwP.

Another way to build upon these guidelines is to investigate how to adapt interfaces to the state the PwP are experiencing at any given moment. Findings pointed to the existence of fluctuations in PwP which are likely to affect the interaction with the smartphone. However, different ways of adapting interfaces for PwP were not evaluated. Future work could concentrate on detecting difficulties in interaction (e.g. less dexterity, dyskinesia episodes) by tracking the speed and accuracy of touches, and then adapt the interface, for example regarding target size areas or tolerance to selection errors. Besides being able to adapt the interface to their users, this work could also contribute to tracking the symptoms of the condition, as it would indirectly monitor the symptoms of the condition.

It is also possible to further this work by applying the guidelines that arose from this research to the design of user interfaces for PwP of a specific project, to then analyse the results and provide further insights into their evidence and validity.

Broaden test conditions. One interesting line of work would be to evaluate the gesture performance of PwP while on Off phase. Findings show that PwP can interact with smartphones when they are on the peak of their abilities. However, it would be important to understand whether this performance is maintained (or severely affected) when their fine motor skills are at their worst stage. By studying the Off phase one can ensure that devices for PwP are appropriate, even when they are at their worst condition.

Another area of work would be to replicate this study with other gestures (such as pinch, spread, and touch and hold) and with a population of older adults. The performance of tap and swipe gestures were already compared in this study, as previous work with older adults investigated these gestures in similar circumstances. However, drag and multiple-tap have not been evaluated with older people. By evaluating the performance of PwP against older adults for these gestures, one will be able to assess whether limitations were age-related, or a result of PD alone.

Finally, it would be interesting to investigate if these guidelines would be applicable to user interfaces that are specifically targeted at people with motor impairments in the upper body or other populations with fine motor skills issues.

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